Rock Mechanics for Natural Resources and Infrastructure Development – Fontoura, Rocca & Pavón Mendoza (Eds)
© 2020 ISRM, ISBN 978-0-367-42284-4

Risk analysis of limestone open pit mine slope stability in Rembang district, Indonesia

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ABSTRACT: The volume of potential failure in a limestone pit located in Rembang has been estimated in previous researches but the risk rating has not been determined yet. In this paper, the determination is carried out by using the failure probability value of the most potentially failed slope and the available estimated volume. The result shows that the risk is categorized as moderate to high level of risk, and from the sensitivity analysis, the variables that influence the most to the safety factor are LG's unit weight and cohesion and HG's friction angle.

1 INTRODUCTION

PT X is an open-pit limestone mine located in Rembang, Central Java, Indonesia. In order to expand the mine to the north, it is necessary to do the slope stability analysis of its slope design. It has been stated in Azizi et al (2018) that for a single bench of each lithology with slope angle at 80°, the estimated volumes of potential failure are 181 and 163 m^3. Additionally, Hartanti (2018) has also concluded that the location with the lowest 3D safety factor (SF) is at the north of the pit with the SF 2,01 and estimated volume of the potential failure 185,000 m^3 using Cuckoo Search and 190,000 m^3 using Grid Search. Thus, the amount of the impact has been discovered. However, to know how great the risk is, it is essential to do the risk analysis.

Quantification of risk of slope failure can be done by multiplying the failure probability (FP) with consequences of slope failure. Consequences of slope failure consist of the occurrence of fatalities and/or injuries to workers, loss and/or damage to company's properties, loss of reserves, environmental damage, and the cost for handling slope failure materials. One of the biggest impacts for the company is absolutely the cost that must be incurred due to the slope failure. To prevent this happening, it must be ensured that the potential failure is still in control. References that discuss further about risk analysis in open-pit mine can be seen in Contreras et al (2006), Tapia et al (2007), Read & Stacey (2009), Azizi et al (2011), Wattimena et al (2012), Kramadibrata et al (2012), Wattimena et al (2013), Kramadibrata et al (2013), Azizi et al (2013), Azizi et al (2014), Ardhi et al (2017), and Abdullah et al (2018).

In this article, risk analysis of the potential failure in an open-pit limestone mine in Rembang, Central Java, Indonesia that is focusing on one of the consequences, the volume of the potential failure, has been done. Engineers in Indonesia are often too optimistic about their slope design. Even though the design has been concluded stable from the geotechnical assessment, risk analysis is still a crucial thing to do. By determining the risk rating of the potential failure, the hazard of the potential failure at the slope can then be assessed. Therefore, if the risk is determined, the company can manage the risk that can happen anytime so the impact or fatality can at least be minimized. It is hoped that this approach can be used to analyze the risk of potential failure in future cases in Indonesia.

2 METHODOLOGY

The object in this article is the slope of PT X's open pit limestone mine in Rembang, Central Java Province, Indonesia consisting of 2 types of rock, namely high-grade (HG) and low-grade (LG) limestone. The 3D analysis result (SF and the location of the potential failure and its estimated volume) is adopted from Hartanti (2018). In order to get the FP, a section at the north slope of the 3D pit model in Hartanti (2018) (Figure 1) is analyzed in 2D using "Bishop" limit equilibrium method in drained condition with Monte Carlo sampling method. For the slip surface, as stated in Hartanti (2018) and Azizi et al (2019), because the use of Grid Search in determining the slip surface in 3D analysis is ineffective and the number of points in the grid box determines the accuracy of the result, Cuckoo Search is then used in this analysis and the result will be compared with 3D analysis result using Cuckoo Search since the comparison should be made fair. Cohesion, friction angle, and unit weight are set as the random variables. The tensile strength data for HG and LG are 2550 kPa and 2250 kPa and it is not set as a random variable. The data that is used is the same as in Hartanti (2018), but for probabilistic purpose the other information, such as distribution type, standard deviation, relative maximum and minimum values, is defined as shown below.

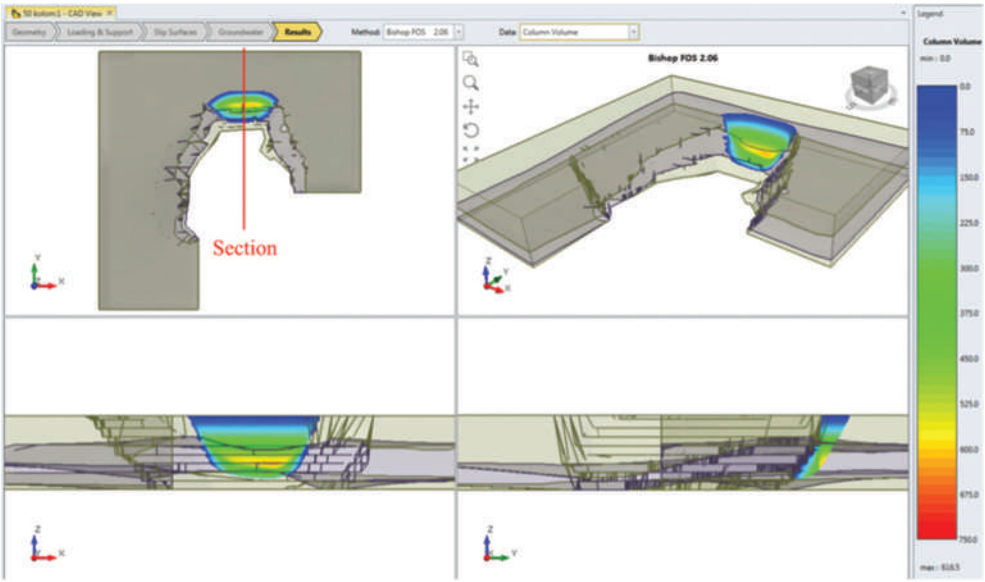

Figure 1. 3D analysis of whole pit result using Cuckoo Search (Hartanti, 2018) and the location of the section for 2D analysis.

Table 1. Random variables for 2D slope stability analysis.

Lithology	Random variables	Distribution	Mean*	Std. dev.	Rel. min.	Rel. max.
HG	Cohesion (kPa)	Normal	250	62.5	187.5	187.5
	Friction angle (°)	Normal	40.7	10.2	30.5	30.5
	Unit weight (kN/m^3)	Normal	20.43	5.11	15.32	15.32
LG	Cohesion (kPa)	Normal	230	57.5	172.5	172.5
	Friction angle (°)	Normal	40.1	10.0	30.1	30.1
	Unit weight (kN/m^3)	Normal	19.79	4.95	14.84	14.84

*Adopted from Hartanti (2018)

Table 2. Semi-quantitative risk matrix with modification.

Likelihood level (FP)	Descriptor	Consequence level				
		0.1	1	10	100	1000
		$0-0.1 million	$0.1-1 million	$1-10 million	$10-100 million	$100 million-1 billion
		Insignificant	Minor	Moderate	Major	Catastrophic
1	Almost certain	2	2	1	1	1
0.1	Likely	3	2	2	1	1
0.01	Possible	4	3	2	1	1
0.001	Unlikely	4	4	3	2	1
0.0001	Rare	4	4	3	2	2

*Risk rating: 1 = Extreme; 2 = High; 3 = Moderate; 4 = Low

Due to lack of data, the distribution types of all random variables are assumed to be normal. In order to ensure the convergence of calculation, the number of samples that are used are 5000, 10,000, and 15,000. The correlation coefficient between cohesion and friction angle is also taken into account and -0.5 is used to define the relationship as suggested by Rocscience (2019).

Finally, the risk rating is determined based on the risk matrix modified with consequence level table in DIIS Australia (2016) (Table 2). Sensitivity analysis is also carried out to obtain which parameter or variable that needs to be concerned.

3 RESULTS

The recapitulation of the results of three simulations can be discovered in Table 3. All results generate the SFs that are higher than one, and based on Read & Stacey (2009) it is still in the acceptable domain.

From Figure 3, it can be seen that convergence graphs of simulations with 5000 and 10,000 samples are still fluctuating but when the number of samples is made 15,000 the graph seems to have a plateau even though it is not constant yet. Based on Rocscience (2019), users can determine whether or not the probabilistic analysis result has converged to constant values from convergence plot. If it does not converge to constant values then the number of samples should be increased. Because the result from computation with 15,000 samples produces relatively constant values at the end and the consideration to increase the number of samples is found ineffective, the constant values can be considered reached. Therefore, the simulation is terminated at the simulation using 15,000 samples. Since there is no excessive difference between these results, the SFs and FPs are averaged to obtain the risk level (SF of 1.782 and FP of 0.23%).

Based on the modified risk matrix (Table 2), this result indicates that the FP is in unlikely category in the likelihood level, while the cost for mitigating the potential failure (approximately $185,000) is in minor category of consequence level if the cost per cubic meter is assumed to be around $1. Hence, the risk rating can be categorized as low. This result shows that the company may only need to do routine monitoring at the slope that has the lowest SF from the 3D analysis, which is the north slope of the pit.

Furthermore, sensitivity analysis is also carried out to determine the variables that affect the stability of slope (Figure 4). Generally, the higher the unit weight of materials, the lower the SF will be, and the greater the cohesion and friction angle of materials, the higher the SF becomes. It also seems that every variable affects the SF value in their own proportions but the most variable that influence the most are LG's unit weight and cohesion and HG's friction angle. Unlike LG's unit weight, HG's unit weight only affects the value slightly.

Table 3. Recapitulation of 2D analysis results.

Section	Number of samples	SF(mean)	FP (%)
North	5000	1.782	0.2
North	10,000	1.784	0.33
North	15,000	1.787	0.16

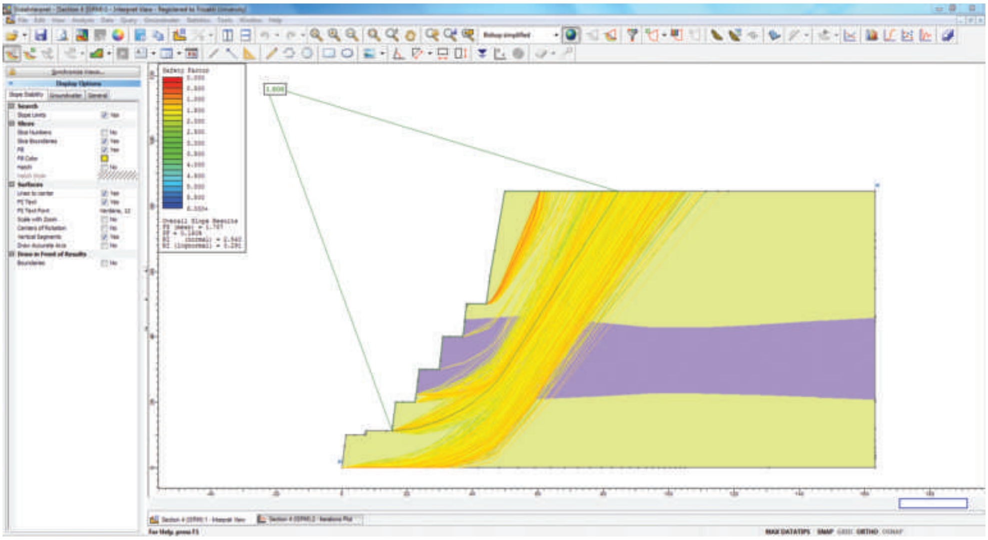

Figure 2. 2D analysis using 15,000 samples (HG is assigned as lime and LG as purple).

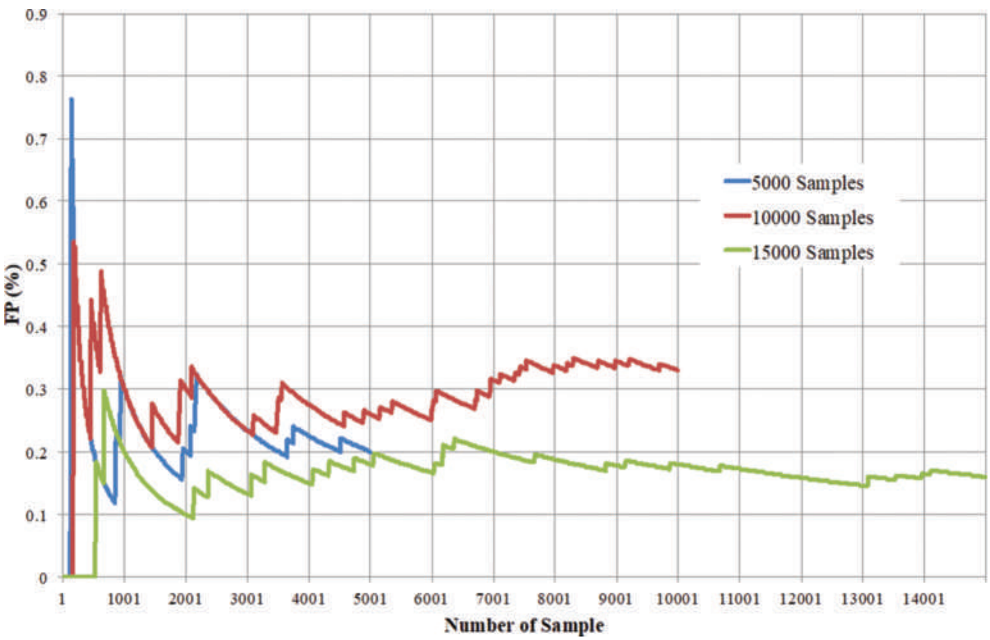

Figure 3. FP (%) convergence plot for each simulation with different number of samples.

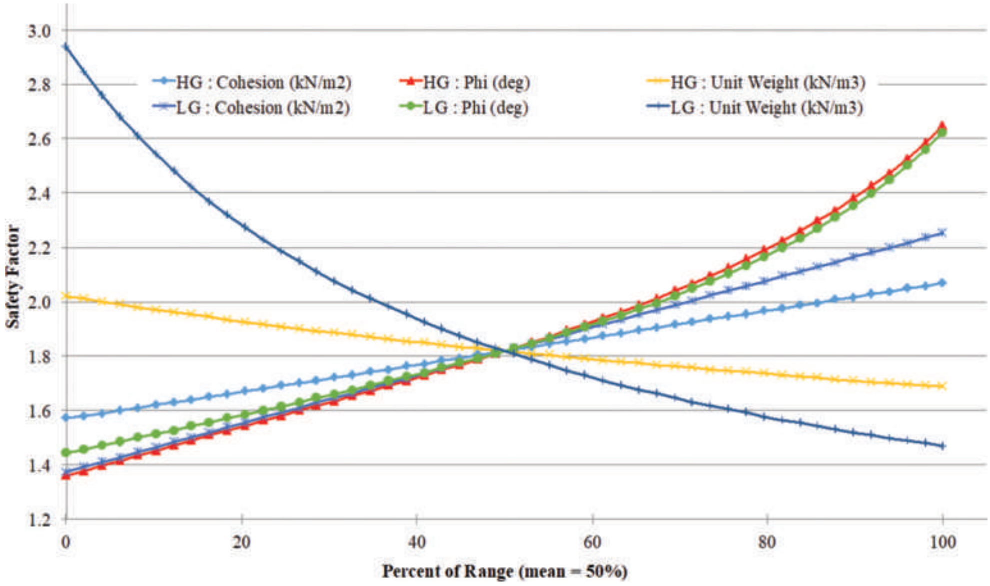

Figure 4. Sensitivity plot of all variables.

4 CONCLUSION

The analysis shows that the overall slope at the north of the pit has SF of 1.784 and FP of 0.23% and the risk rating is low. The variables that might need to be taken as a concern in future in order to reduce the fatality are LG's unit weight and cohesion and HG's friction angle, as these variables bring the most influence to the SF.

ACKNOWLEDGEMENT

Authors would like to thank Mining Engineering Department, Faculty of Earth Technology and Energy, Universitas Trisakti in facilitating the software and Rocscience, Inc. as the provider of Slide software to support this paper.

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